

# Vegetated Wire Mesh Mattress with Sand Filling, a Technique of *Posidonia Oceanica* Re-Planting in the Coastal Waters of Elba's Island (Italy)

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**\*Corresponding author:** Nicola Cantasano, National Research Council, Institute for Agricultural and Forest Systems in the Mediterranean, Rende Research Unit, Italy

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**Nicola Cantasano<sup>1\*</sup> and Federico Boccalaro<sup>2</sup>**

<sup>1</sup>National Research Council, Institute for Agricultural and Forest Systems in the Mediterranean, Rende Research Unit, Italy

<sup>2</sup>AIPIN Lazio, Member of EFIB, European Federation of Soils Bioengineering, Section of Italian Association for Soil Bioengineering, Italy

## Abstract

Restoration processes, through transplanting operations, represent a reliable approach to enhance the recovery of *Posidonia oceanica* meadows in the Mediterranean Sea. The environmental issue, regarding the need of this study is to summarize some kinds of Soil Bioengineering, commonly used in terrestrial landscape, also in marine environments. Amongst the main techniques, it has been realized, on October 2006, an experimental test regarding the transplantation of *Posidonia oceanica* (L.) Delile shoots on the marine depths of Elba's Island (Italy). These kinds of coatings, are formed by vegetated wire mesh mattresses with sand filling. The first results of this trial show the positive outcomes of the experiments but, at the same time, the slowness of recovery actions, suggesting the potential to extend such methodologies, typical of terrestrial defense, to marine environment.

**Keywords:** *Posidonia oceanica*; Soil Bioengineering; Mattresses; Elba's Island

## Introduction

Seagrasses are marine angiosperms able to support healthy coastal ecosystems maintaining the ecological, physical and geological processes in marine biosphere [1-4]. Amongst seagrass species, *Posidonia oceanica* (Linnaeus) Delile, is one of the most important endemic species of Mediterranean Sea. In good and pristine conditions of coastal seawaters, this marine plant, can form large and extensive meadows, covering a global surface area estimated as 23,000km<sup>2</sup> [5]. *Posidonia* beds represent the typical "climax" ecosystem of the basin [6,7] in the infralittoral bottoms of Mediterranean Sea on mobile and hard substrata from surface waters to 40-45 meters depth, according to light conditions. So, valuing the important ecological roles performed by the meadows, *Posidonia* beds are protected by European legislation through the Habitat Directive (92/43/UE), classified as "Priority Habitat" and inserted as "Best Concern" ecosystem within the Red List released by the International Union for Conservation of Nature (IUCN) [8]. However, despite all these legislative efforts, the meadows are, actually, affected by a widespread regression with a declining trend variable from 13% to 50% [9,10]. This negative trend is caused by conditions of marine pollution induced by human impacts [11-13], by mechanical erosion [14,15] and by burial processes [16-18]. Therefore, the protection of the meadows has become one of the main targets within a sound management of Mediterranean seawaters. In this way, *Posidonia oceanica* seagrass, is one of the main Nature-Based Solution (NbS) for coastal protection, since it may reduce wave action and sediment transport in coastal areas, so to mitigate erosion risk [19]. Active restoration, through transplanting techniques, becomes a reliable approach to enhance the natural recovery of *Posidonia* meadows. In these last decades, many efforts have been realized in Mediterranean Sea [20,21] but experimental evidences highlight the failure of some trials

[22]. The transplanting techniques are distinguished by scientific literature [10,23,20] in the following ones:

- A. cement with holes;
- B. cement frames around wire meshes retaining cuttings;
- C. metallic, plastic or biodegradable wire grid laid flat on the bottom, retaining cuttings;
- D. fixing the cuttings to the bottom by means of stakes or staples;
- E. digging of holes in which blocks are placed;
- F. planting of seedlings germinated in laboratory;
- G. planting of seeds collected at sea or on beaches.

Amongst these experimental measures, the C techniques have been performed in some Mediterranean regions as in Provence, French riviera, Corsica, Tuscany and Sicily [24-31]. Such measures are distinguished in mattresses, biological and/or geotextile mats being part of Soil Bioengineering, a specific discipline of environmental engineering. It pursues technological, ecological and economic as well as design goals. In this way, it seeks to achieve these results primarily by making use of living materials, i.e. seeds, plants, parts of plants and plant communities, employing them in near-natural constructions and exploiting the manifold abilities inherent in plants. Soil Bioengineering may be a substitute for classical engineering works and, in most cases, it is a meaningful and necessary method of complementing the latter. The application of Soil Bioengineering tools is suggested in all fields of soil and hydraulic engineering, especially for slope, embankment stabilization and erosion control.

This study analyses a similar kind of technique normally used by Soil Bioengineering on terrestrial environments but applicable

also in marine ones. The experimental trial consists in laying down, on marine depths, wire mesh mattresses with sand filling coated with geotextile membranes, where cuttings of *Posidonia oceanica* are fixed.

## Materials & Methods

The experimental trial, conducted for the re-vegetation and the consolidation of marine depths, through the transplanting of *Posidonia oceanica* plantlets, with intact leaves and rhizomes, was realized along the coastline of Elba's Island just in front of the sandy beach of Cavo bay. This research, realized in three years from October 2006 to March 2009, was tested to evaluate the resistance of these materials, normally used by Soil Bioengineering in terrestrial environments.

## Study area

The island of Elba, the main islet of Tuscan Archipelago, is located in the Western Mediterranean basin, along the Northern Tyrrhenian Sea of Italian seaboard. Elba is the third Italian island for its extension. It shows a global surface area of 224 square kilometres and a length of its coastline of 147 kilometres. The island shows a triangular shape, appearing irregular in its coastal outline, interrupted by many gulfs, bays and headlands. The geological formations of the sandy beaches are variable from sands to gravels and pebbles. The submerged beach of Cavo bay, characterized by *Posidonia oceanica* meadows, on a depth of about 5 meters, represents the study area of the research (Figure 1). It is composed by fine sands and pebbles with a lot of plate fractures filled with quartz highly deformed by veins within the typical "Cavo Formation" [32]. Finally, on the marine depths Cavo bay it was shown a regression of *Posidonia* meadows caused by human activities, as confirmed, also, by the presence of some dead "mattes" widespread on soft marine bottoms.



**Figure 1:** Geographic map of Elba's Island and detail of the study area with geographical coordinates 42°51',729 N, 10°25',221 E located in the bay of Cavo and marked with a red circle.

## Materials

The experimental trial, for the re-vegetation of marine depths, was realized through the use of mattresses and *Posidonia oceanica* cuttings. During the field trial pre-assembled modules, known as mattresses, were used. These kinds of mats were coupled with

double twisted wire meshes, covered with geotextile materials and filled with sands and/or pebbles. The geotextile materials, as “Macmat R” square tables, were dissected in plots by 1m x 1m dimensions and the mattresses were lined with geo-texture coverings. Finally, cuttings of *Posidonia oceanica* species were fixed singly on the mats (Figure 2).



**Figure 2:** Mattress for re-vegetation of marine depths with transplanted cuttings of *Posidonia oceanica*.

**Sustainable engineering:** Amongst the different kind of mattresses, combining sustainability and performance, it was tested the PoliMac® mattress. This specific kind of coating, composed by biodegradable materials, ensures exceptional durability, reducing maintenance and extending the product’s life cycle. Rigorously tested, it does not release harmful substances into water. By using natural stone, these solutions integrate seamlessly into aquatic environments, enhancing biodiversity. With over 70% less material

usage compared to rip-rap, they deliver the same performance with a lower environmental footprint.

**Verification of the mattress stability on marine depth:** Before the planting operations, it was tested the resistance of the mattress against the pulling and the raising forces of hydrodynamics existing in the transplanting site, on the base of weather and climatic conditions prevailing in the bay of Cavo (Table 1).

**Table 1:** Verification of mattress stability in the marine depth of transplanting site (from Matteo Zanella Coastal Protection System, Maccaferri S.p.A., Bologna, Italy).

Wave Data	Symbols	Values	Units
Gravity acceleration	G	9.806	m/s <sup>2</sup>
Height	H	2.1	m
Period	T	10	s
Depth	D	5	m
Wave lenght	L	67.68	m
Bottom values	Symbols	Values	Units
Orbital velocity	U <sub>orb</sub>	1.37	m/s
Orbital acceleration	AC <sub>Corb</sub>	0.86	m/s <sup>2</sup>
Current velocity	U <sub>corr</sub>	0.5	m/s
Forces values	Symbols	Values	Units
Friction coefficient	μ	0.8	-
Water Specific Weight	ρ <sub>w</sub>	1028	kg/m <sup>3</sup>

Lift coefficient	CL	1.5	-
Drag coefficient	CD	1.5	-
Inertia coefficient	CM	3	-
Lift force	fL	618.9	N/m
Inertia force	fi	609.2	N/m
Drag force	fd	618.9	N/m
WEIGHT VALUES	$W_s = [(F_d + F_i + \mu * F_d) / \mu]$	219.7	kg/m
<b>Mattress characteristics</b>	<b>Symbols</b>	<b>Values</b>	<b>Units</b>
Mattress thickness	-	0.23	m
Submerged weight required	-	2154.1	N/m
Mattress weight on air	-	2400	kg/m <sup>3</sup>
Water specific weight	$\rho_w$	1.025	kg/m <sup>3</sup>
Mattress length	L	1	m
Mattress width	B	1	m
Void	void	80%	-
<b>Mattress weight in water</b>	<b>Verification satisfied</b>	253	kg

## Methodologies

The actions made during the field campaign were firstly realized on the ground to characterize the biotic and abiotic conditions existing in the marine depths of the study area. Then, it was prepared, in laboratory, the main kind of mattresses used for transplanting experiments. In the third stage of the planning activities, it was realized, directly on the marine depths of Cavo's bay, the sinking of the mats and the following transplanting of *Posidonia oceanica* cuttings. The planting was realized following some steps, as suggested by scientific literature [33], as are:

- A. Preliminary assessment of a planning scheme to evaluate the effectiveness of planting operations.
- B. Characterization of experimental sites and evaluation of *Posidonia oceanica* meadows in the donor sites and in the receiving ones.
- C. Identification of the most suitable transplanting techniques.
- D. Sorting of *Posidonia oceanica* plants for planting activities.
- E. Control of transplanting cuttings in time.
- F. Monitoring of the main positive and negative outputs of the interventions.

## Work phases

In particular, the planting activities are distinguished in the following steps:

- a. assessment of the installation plan through earthmoving works;
- b. setting of mattresses on beaches or on supporting vessels and connection of different modules using wire meshes;

- c. on marine depths, subjected to high hydrodynamic forces, it is suggested to anchorage the mats to the bottoms with metallic grids and/or with ballast waters to guarantee a better stability of the whole structure;
- d. filling voids with sands, pebbles and/or with organic fibres;
- e. use of surface coatings on the upper floor of mattresses with biological or synthetic mats;
- f. closing the mattresses in the upper sections;
- g. transplanting of *Posidonia oceanica* cuttings;
- h. sinking the whole structure on the selected marine depth.

The operative stages of the project were based firstly on a global withdrawal of 45 orthotropic rhizomes and fifteen plagiotropic ones from donor meadows of *Posidonia oceanica*. In the second stage of the project, the 60 detached cuttings were transplanted in three plots, by dimensions of 1m x 1m, represented by three "Reno" mattresses, all located on the marine depths of Cavo's bay. In this marine experimental station, located, at a depth of about 5 metres, were located two underwater drills measuring continually light and temperature values. The experimental trial, beginning in October 2006, went on for about three years until March 2009.

## Monitoring

To test the outcomes of transplanting experiments, it has been prepared a structured monitoring plan, yearly from 2010 to 2019, with the use of specific collecting forms to verify, after the planting of *Posidonia* shoots, the following parameters:

- a) the surviving rates of transplanted rhizomes;
- b) the growing rate of the transplanted leaves;
- c) the formation of new apical rhizomes;

d) the vegetative recovery of transplanted cuttings.

All these steps, representing the core of the experimental design, show that transplanting is a complex procedure that must be realized through a series of stages in a consecutive order for the successful output of the process.

The delay in communicating the resulting data is due to the need to wait the final results of a project nicknamed Life SEPOSSO [34], conducted in the bay of Cavo of Elba's Island from 2019 to 2020 within an experimental plan realized by the International School for Scientific Diving (ISSD). The aim of the project is to realize a reforestation plan with *Posidonia oceanica* plantlets using wire mesh mattresses, as already tested in previous experiments within

techniques of Soil Bioengineering. The monitoring plan realized in the period 2020-2024 show that all the structures are stable with surviving rates of *Posidonia* shoots as 55% and rhizomes as 58%.

## Results

The installation on marine depths of "Reno" mattresses and "Macmat R" coverings was preceded by a complex stage realized on the ground for a correct preparation of the materials (Figure 3). Afterwards, in October 2006, the mattresses were carried away directly at sea where the square tables were fixed both on sands and on dead "mattes" of *Posidonia oceanica* meadows by using steele stakes (Figure 4).



**Figure 3:** Setting on the ground of "Reno" mattress.



**Figure 4:** Planting mattress on the marine sandy bottoms at the transplanting site.

Since from the beginning, the plant cuttings, sustained by soft and spongy materials, without further fixing systems, appeared well established and began to radicate, extending roots from their rhizomes. In next months were performed a series of controls to point out the conservation status of the materials used in seawaters. At the same time, it was checked the stability of the cuttings in a general context of high hydrodynamics. In the first of these surveys, realized one month after the former installation, it was observed a good conservation status the “Macmat R” square covering, located on the dead “matte”, showing a total integration in the benthonic

marine environment. As a matter of fact, it was observed the growing of the seaweed *Caulerpa prolifera* (Forsskål) Lamouroux, already present in the study area (Figure 5). In the next surveys, realized in 2007 summer season, after strong sea storms, all the planted structures, showed a good conservation status and, also, the anchorages of the materials appeared stable and effective. So, after two years from the beginning of the experiment, it was observed a total integration of the mattresses in marine environment, as confirmed by the full infiltration of marine macroalgae in the tridimensional structure of the mats (Figure 5).



**Figure 5:** Integration of the mattress with the seaweed *Caulerpa prolifera*.

In the following survey, after two years from the beginning of the transplanting experiment, the mattresses were fully integrated with marine depths allowing the gradual growing of marine

vegetation, as *Acetabularia acetabulum* (Linnaeus) P.C. Silva, completely covering the planting plots (Figure 6).



**Figure 6:** Transplanted cuttings of *Posidonia oceanica* surrounded by the seaweed *Acetabularia acetabulum*.

The last field survey, conducted in March 2009, confirmed the solidity of the whole structure and the high capacity of “Macmat R” mattresses fully integrated in the dead “matte” of *Posidonia oceanica* meadows. Finally the transplanted cuttings of *Posidonia oceanica* showed a good state of conservation and a fair elongation

of their radical systems (Figure 7) with a slow growth rate variable from 1 to 7cm for orthotropic rhizomes and 2-4cm for plagiotropic ones with a surviving rate of about 70%. These results confirm the right choice of marine depth and the good performance of transplanting technique.



**Figure 7:** Successful stage in transplanted cuttings of *Posidonia oceanica*.

## Discussion

This study was based on field observations and the measurements done on the transplanting cuttings were recorded especially regarding the variables related to growth performance of *Posidonia oceanica* species. The first results of the field survey suggest that “Reno” mattresses and “Macmat R” squares are stable and, therefore, could be usefully applied for reforestation projects realized with *Posidonia oceanica* or with other species of seagrasses. This option is becoming possible because mattresses are characterized by a marked stability on marine depths and by a high resistance against hydrodynamics. Indeed, these kinds of measures are easy to prepare directly on the ground and can be realized at low-cost. In particular, from the resulting data, it appears

especially useful the application of “Macmat R” coverings fixed on “dead mattes” of *Posidonia oceanica* meadows and coupled with the presence of natural seaweeds.

The experimental trial highlights the need to insert *Posidonia* cuttings directly in the cover of the mattress before its final assessment on marine depth. In this way, it is possible to integrate the radical systems of transplanted cuttings in the sediments, fixing the whole structure on marine depth. The resulting data, based on field observations, show the resilience of transplanted shoots with a slow recovery in time (Figure 8), suggesting that a fair plant recovery is appreciable just after three years, as confirmed, also, by scientific literature [29,22,35].



**Figure 8:** Cuttings of *Posidonia oceanica* stably fixed and deeply rooted in the sediments.

From the resulting data it is possible to confirm that the use of mattresses, fixed with wire stakes on hard substrata and on patchiness marine depths, is better than biological and/or geotextile mats. In fact, the transplanting of *Posidonia oceanica* cuttings on rocky surfaces needs ballast means while bio-mats are more suitable on large and regular sandy seabed, as observed in the described experiment (Figure 9) [36]. Anyway, in both cases, the cuttings are able to firmly take root because the coverings

of the mattresses are made with the same materials [37]. In transplanting operations, it is always suggested to use cuttings of *Posidonia oceanica* already detached from the meadows by wave motions and/or by human pressures such as anchoring or trawling activities. In this way, it is possible to limit the withdrawal effects from donor meadows, so reducing the environmental impact on coastal habitats [38].



**Figure 9:** Biological mats, in agave fibres, re-vegetated with *Posidonia oceanica* cuttings and fixed with wire stakes on marine depths.

Finally, some experiments, conducted on the marine depths of Balearic Islands in the Western Mediterranean Sea, tested the use of *Posidonia oceanica* seedlings produced by beach-cast fruits collected on the beach. The planting of seedlings was realized on a dead mat of *Posidonia* meadow. The trial showed a global survivorship of about 50% of the transplanted seeds where each seedling was able to produce from one to four shoots after three years from the beginning of the experiment [39].

## Conclusion

The resulting data show that the materials tested in transplanting experiments, especially Macmat R" mattresses fixed on dead "mattes", can be successfully used for the re-vegetation of marine depths with *Posidonia oceanica* plantlets. This study provides useful data helping coastal managers to really understand the transitions between local areas of transplanting cuttings and well-established reforestation planning. However, the main issue regarding these kinds of programs in the Mediterranean Sea deals with experiences conducted in short terms [40-43] and rarely in long times [29]. These constraints are caused by the short duration of many projects, by short-term fundings and/or by the need to publish quickly the resulting data. Indeed, policy

makers, media coverage and public opinion are more interested in larger operations at high profile, while the projects, aimed to the improvement of environmental conditions, are limited by financial means.

Anyway, the gradual regression of *Posidonia oceanica* meadows in the Mediterranean Sea is becoming a real environmental emergency. At the same time, it is necessary to remove possible stressors in marine environment allowing ideal conditions for a full natural recovery of coastal ecosystems [44,45]. In this way, to pursue an effective protection of *Posidonia* meadows, long-term restoration processes should be tested at individual and ecological levels.

In conclusions, the main goal of these experimental trials it is not only to recover the original meadows but also to replace damaged areas, as dead "mattes" of *Posidonia oceanica*, with stable meadows.

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